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Determining a Lateral Load Specification for Downcomers during Chugging in a Mark II Containment*

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Abstract

During a postulated LOCA in a BWR containment, steam is vented to the suppression pool and condensation-driven pressure oscillations may occur. In a Mark II type of containment with vertical downcomers these pressure oscillations may give rise to lateral loads near the downcomer exit which are impulsive in nature and random in direction.

Domestic BWR vendors found that a dynamic load having a half sinusoidal shape with maximum amplitude F and duration τ, when applied to an analytic model of a Mark II downcomer, reproduced well the structural response observed in domestic and foreign lateral load tests. Because of the relative time scales involved, this could be thought of as an impulse specification with an impulse of amplitude F.

Since observations showed a lower limit on the duration τ of 3 ms and that the smallest durations led to the highest amplitudes and highest impulses, the crucial part of choosing an appropriate specification was reduced to assigning a value to the amplitude F.

Originally, the highest load observed in a domestic test conducted for the Mark II Owners had been suggested as an appropriate specification. At the request of NRC, Brookhaven National Laboratory and its consultants evaluated the results of several foreign and domestic lateral load tests in order to recommend an appropriate load amplitude. In these various tests, peak values were consistently higher in tests with larger data bases and high loads occurred more frequently in tests of longer duration, i.e. with more recorded lateral loads. Moreover, since all the significant lateral load data came from single vent test facilities, the number of lateral loads recorded in any one test was small compared to the number which could be expected to occur in a postulated LOCA in an actual Mark II plant which has approximately 100 downcomers. None of the tests provided evidence of an upper bound. A roughly exponential fit for load magnitudes versus probability of exceeding a particular load was found in all the test data. Based on this fit, a load magnitude more than twice the highest observed amplitude was extrapolated and specified as design value to reduce the probability of exceeding this load at any one downcomer to less than 0.1 per LOCA.

1. Background

During a postulated LOCA in a BWR containment, steam is vented to the suppression pool and condensation-driven pressure oscillations may occur. In a Mark II type of containment with vertical downcomers these pressure oscillations may give rise to lateral loads on the downcomer. These lateral loads occur near the downcomer exit and have been observed to be impulsive in nature and random in direction. In containment design, both the lateral loads on individual downcomers as well as the effect of groups of laterally loaded downcomers on other containment components must be considered.

Previous investigators found that a dynamic load having a half sinusoidal shape with maximum amplitude F and duration τ, when applied to an analytic model of a Mark II downcomer, reproduced well the structural response observed in domestic and foreign lateral load tests.

Since τ was of the order of milliseconds and the period of oscillation of the downcomer is usually much longer, this could be thought of as an impulse specification where the impulse I is given by:

$$I = F \int_0^{\tau} \sin \frac{\pi t}{\tau}\, dt = \frac{2\tau}{\pi} F.$$

Observations showed that the smallest durations led to the highest amplitudes and highest impulses. Since a lower limit of τ on the order of 3 ms was observed, the crucial part of choosing an appropriate specification was reduced to assigning a value to the amplitude F.

Originally, obtaining F from the highest load observed in a domestic test (referred to as the 4T Tests [1]) conducted for the Mark II Owners had been suggested as an appropriate specification. A dynamic amplitude of 30 kilopounds was thus proposed. The philosophy of the Mark II Owners Group was that since this load comfortably bounded all the other data points in this test series, it represented an upper bound for Mark II lateral loads and no lateral loads in excess of this value would be found to occur in a Mark II plant.

However, when the Owners examined lateral load data from three foreign chugging tests, all of these tests showed maximum dynamic loads of roughly similar magnitudes to the highest load in the 4T Tests which was supposed to represent an adequate bounding value. Moreover, the number of chugs available in each of these tests - or in all of them together, for that matter - was far less than the number that may occur in a typical LOCA. As a result, the USNRC became concerned that either the suggested bounding load was too low, and/or a true physical bounding load had not been measured in any of the available data bases, which merely reflected a statistical distribution of chug strengths characteristic of the randomness in the chugging process.

In March 1981 the USNRC asked the Owners to examine their lateral load data from the viewpoint of a probability distribution, and at the same time began making its own statistical investigation of the available data by requesting Brookhaven National Laboratory (BNL) and its consultants to evaluate the results of several foreign and domestic lateral load tests in order to recommend an appropriate load amplitude.

2. Data Base

Besides the 4T Tests [1] mentioned previously, lateral load measurements made in one other domestic and three foreign test series were considered in the statistical evaluation. The domestic test series designated 4TCO [2] was carried out on the modified site of the original 4T Tests. The three foreign tests are commonly referred to as GKM-II [3], GKM-II-M [4], and the KWU-Karlstein [3] Tests. Of these, the GKM-II [3] Tests were the most significant for statistical analyses. Lateral-load data from this full-scale, single-vent, prototypical foreign licensee facility are the most extensive data base for lateral loads from any one prototypical facility. Lateral-load data were recorded during blowdowns which covered all of the Mark II conditions and even went outside the Mark II range. The staff used this data base as its primary source for the statistical evaluation of the single-vent lateral loads. While not all data from all tests were available and while the data were for the most part in terms of brace loads and not tip-load resultants, these data still made up the most comprehensive base for statistical purposes.

The results of nine GKM-II tests were utilized in the study by BNL and its consultants. These tests covered various conditions of mass-flow and pool temperature which represent much of the chugging map applicable to Mark II conditions. Exceedance probabilities were determined for each of the tests and for the whole body of data.

Appendix B of Ref. [3] lists, for each chug, the peak values of compressive and tensile forces in each of the two braces holding the downcomer, for the nine tests. There are thus four brace load values given for each chug, and the data comprises some 2000 usable chugs, divided into 9 different pool temperature/mass flow conditions.

To use the data one has first to convert the peak individual brace loads to a peak vector brace load, and then the vector brace load to an equivalent 3 ms load amplitude. The second step has been done, via a numerical model, in Ref. [3]: the value of F is equal to about 1.9 times the peak resultant brace load. The first step, however, is not possible to take with rigor without the availability of the entire brace load histories for each chug. The assumption was made that the exceedance probability for the peak resultant brace load is equal to the exceedance probability for the peak (positive or negative) individual brace load. Thus, all four values of Appendix B for each chug were used to generate the distribution.

3. Definitions of Exceedance

In what follows the load F is an equivalent load amplitude, defined in such a way that a vector load with a half-sinusoidal form having load-amplitude F and duration τ = 3 ms will produce the observed structural response in the downcomer. This load F really represents an impulse specification, since the impulse due to a lateral load characterized by F is, by definition,

$$I = F \int_0^\tau \sin \frac{\pi t}{\tau} \, dt \qquad (1)$$

If F is measured in klbf, and τ equals 3 msecs,

$$I = 1.91 \ F \ \text{klbf} \cdot \text{msec.}$$

The exceedance probability of the load F is defined as:

$$P(F) \equiv \frac{\text{No. of chugs with force} \geq F}{\text{total No. of chugs in data base}} \qquad (2)$$

The probable number of exceedances N(F) of the load F in one LOCA will thus be

$$N(F) = (\text{No. of chugs in LOCA}) \cdot P(F) \qquad (3)$$

where

$$\text{No. of chugs in LOCA} = \text{No. of vents in system} \times \text{No. of pool chugs in LOCA.} \quad (4)$$

Once the probability distribution P(F) has been established from the pertinent experimental data, one needs only decide how many exceedances of the design load F_d can be tolerated in a LOCA. When $N(F_d)$ has been decided on, the design load itself follows from its corresponding exceedance probability, as given by Eq. (3),

$$P\ (F_d) = \frac{N\ (F_d)}{\text{No. of chugs in LOCA}} \quad (5)$$

4. Results and Conclusions

The data indicate that two of the tests which cover relatively low mass flow and cold pool conditions and together comprised about one quarter of the complete data base, had a higher probability of high-load chugs than the whole body of the data base taken together. The exceedance probabilities for these two tests are shown separately for comparison.

At the low probability/high load end, the experimental probability curves can be fitted with exponential forms

$$P(F) = e^{-\frac{F}{\sigma}} \quad (6)$$

Figure 1 shows the Reference [3] results and the exponential fit. Certain deductions can now be made from the statistical data.

First, there is no indication that 30 klbf represents some "bounding value" of F. The GKM-II data stretch to 30 klbf, and slightly beyond, without any sign of a downturn, such as might be expected when some absolute physical bound of a statistical quantity is approached.

Secondly, consider a LOCA in a typical Mark II plant with 100 downcomers. From Eqs. (3) and (4) one calculates the probable number of exceedances N(F) of the lateral load value F in the LOCA as

$$N(F) = 10^2\ (\text{No. of pool chugs in LOCA}) \cdot P(F) \quad (7)$$

Table I shows the probable number of exceedances of the proposed design load of F = 30 klbf in a 100 pool chug LOCA, and a 265-pool-chug-LOCA which represents an estimate for the longest expected LOCA. The figures show that the 30 klbf load will certainly be exceeded a large number of times in a typical LOCA, and may be exceeded over a hundred times in a very extended, cold-pool LOCA. Note that the numbers in Table I are not based on any extrapolations of the exceedance probability curves: at the 30 klbf level, the exceedance probabilities can be read off directly from the experimental points (Fig. 1).

Table II shows how the load value F affects the number of exceedances of that load in a 100-pool-chug LOCA (to obtain the corresponding numbers in a 265-pool-chug LOCA, add 5.4 klbf to the "COLD POOL" number, and 4.1 klbf to the "TESTS 1-9" numbers).

Clearly, a design load of at least about F = 65 klbf would be required if one wanted to ensure an exceedance probability small compared with unity per LOCA under all LOCA conditions. With this load, the probable number of exceedances would be below 10^{-2} per LOCA based on all the GKM-II data (unweighted) and of the order of 0.1 based on the cold-pool subset of the data.

The data from the various other tests mentioned earlier was unfortunately too limited to allow any deductions about very low-probability, high load occurrences. However, they were not inconsistent with the GKM-II data and, in general, fell nicely into line with that data in the regions where a comparison could be made.

Therefore, a design value of F of 65 klbf (more than twice the highest observed in the 4T Tests), was recommended and adopted as a lateral load specification by the USNRC.

It should be noted that for assessing groups of downcomers, i.e. multivent lateral loads, a much lower amplitude, such as the highest observed values, was considered adequate as a basis for specifying multivent loads. This was due to the phasing occurring between downcomers which makes the probability that two or more vents experience high amplitude loads in the same direction at exactly the same time very small.

A more detailed discussion of lateral load data and its evaluation can be found in References [5] and [6].

References

[1] "Dynamic Lateral Loads on a Main Vent Downcomer - Mark II Containment", General Electric Proprietary Report, NEDE-24106-P, March 1978.

[2] BIRD, P. F., et al., "4T Condensation Oscillation Test Program Final Test Program Final Test Report", General Electric Proprietary Report, NEDE-24811-P, May 1980.

[3] BORHAUG, J. E., "Dynamic Lateral Loads on Mark II Main Vent Downcomer - Correlation of Independent Reference Data", General Electric Proprietary Report, NEDE-24794-P, March 1980.

[4] "Susquehanna Steam Electric Station Design Assessment Report," Revision 3, Book 2, Pennsylvania Power and Light Company, July 1980.

[5] ANDERSON, C., "Mark II Containment Program Load Evaluation and Acceptance Criteria", NUREG-0808, August 1981.

[6] LEHNER, J. and SONIN, A., "Statistical Basis for Mark II Single-Vent Lateral Load", Selected Evaluations of Mark II LOCA Loads Performed by BNL and Its Consultants for the Mark II Generic Program, NUREG/CR-2191, pp. 93-101, March 1982.

TABLE I

NO. OF EXCEEDANCES OF 30-KLBF
LOAD IN A LOCA
(100 DOWNCOMERS)

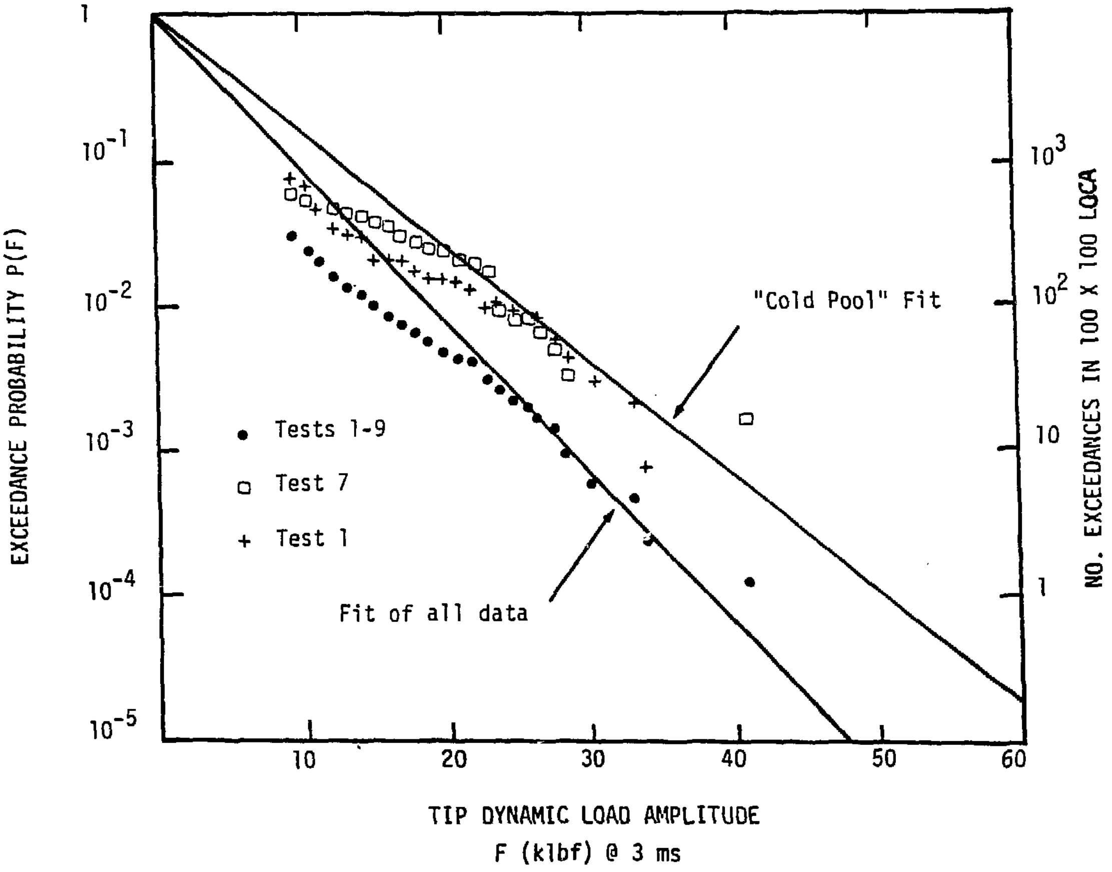
N = NO. OF EXCEEDANCES

	N	
BASIS	100 Pool Chugs	265 Pool Chugs
"COLD POOL DATA"	43	114
GKM-II, TESTS 1-9	7	20

TABLE II

RELATION BETWEEN LOAD AND NO. OF EXCEEDANCES IN 100 x 100 LOCA

NO. EXCEEDANCES, N	LOAD, $F = \sigma \ln (10^4/N)$ klbf	
	GMK-II, TESTS 1-9	"COLD POOL DATA"
10	29	38
1	38	51
10^{-1}	48	63
10^{-2}	57	76



1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
EXCEEDANCE PROBABILITY P(F)
10^3
10^2
10
1
NO. EXCEEDANCES IN 100 X 100 LOCA
"Cold Pool" Fit
● Tests 1-9
□ Test 7
+ Test 1
Fit of all data
10
20
30
40
50
60
TIP DYNAMIC LOAD AMPLITUDE
F (klbf) @ 3 ms

Figure Caption

Figure 1 GKM-II Lateral Load Data